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Original Research

Could rhombic-shaped miniplates be applicable for subcondylar fractures of the mandible? A biomechanical study

Biomechanical analysis of rhombic-shaped miniplates

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Abstract

Aim: Mandibular condylar process fractures are the most common fractures in the maxillofacial region. Surgical treatment of condylar region fractures with miniplates and miniscrews has become more popular because it is a stable method that allows immediate function. The present study examined sheep hemimandibular subcondylar fracture models to evaluate the biomechanical properties of two different miniplate/screw system types used for surgical fixation of subcondylar fractures.

Material and Methods: Experimental standardized subcondylar fracture lines were examined in ten sheep hemimandibula models. Each segment was fixed with one of two fixation types: double straight miniplates with eight miniscrews or a single rhombic-shaped miniplate with five miniscrews. All models were mounted in a servohydraulic testing unit, and a continuous linear force was applied. Maximum force and displacement values were evaluated and statistically analyzed.

Results: The rhombic-shaped miniplate group had statistically significantly lower values than the double straight miniplate group for the maximum force, work at maximum load, and hardness. There was no statistically significant difference between the two groups in terms of the displacement at the maximum load.

Discussion: Considering the advantages of rhomboid mini-plates, further clinical and mechanical studies are needed for their use in the surgical fixation of subcondylar fractures.

Keywords

Bone Fractures, Fracture Fixation, Rigid Fixation, Miniplates

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This study was approved by the Ethics Committee of Mersin University (Date: 2018-05-14, No: E-728620)

Introduction

Condylar fractures account for 25–50% of all mandibular fractures [1]. Fractures in the mandibular condylar area were classified into three groups, according to the anatomical level of the fracture line. Intracapsular or condylar head fractures occur at a high level above the ligament; condylar neck fractures occur on the thin and narrow area just below the condyle head; subcondylar fractures begin from the sigmoid notch and run obliquely to the posterior border of the ramus or the masseteric tuberosity, including the condylar process [2]. This high incidence rate of condylar fractures is explained by the condylar area being the weakest portion of the mandible. Fractures of the condylar region occur mainly when the force applied to other regions of the mandible is distributed and transferred to this area [3]. Due to the complex anatomy of the temporomandibular joint, as well as the surgical proximity of this area to the facial nerve, the maxillary artery, and many other important and vital structures, surgically managing subcondylar fractures and stabilizing the fragments present some challenges and risks [2].

Fracture lines and degrees of fragment displacement vary according to the area of force exertion, the magnitude and direction of force, the patient's occlusal position at the moment of impact, and individual anatomical features.[2] Clinicians face several options and challenges when choosing functional, aesthetic, comfortable, and economical methods. When treating condyle fractures, occlusion, jaw movements, maxillofacial symmetry, and temporomandibular joint functions should be managed, reconstructed, or treated. The options depend on the opinions of clinicians; therefore, there is no consensus concerning the ideal method or material [4,5].

In 1976, the basic principles of functionally stable osteosynthesis using miniplates and miniscrews were defined. The main purpose of this method is to ensure a stable relationship between the fractured and mandibular segments to allow for immediate function. In 1980, internal fixation with miniplates and miniscrews in condyle fractures was reported for the first time in the literature [6]. Since then, further information has been accumulated, indicating that internal rigid fixation via miniplates and miniscrews is the most advantageous treatment option for mandibular condylar neck and subcondylar fractures. Treatment outcomes in these areas have benefited considerably from different miniplate system designs [7–9]. Because of the small volume and thin neck of the condylar region, it is important that the clinician should choose the smallest, thinnest, and few materials that are possible to retain sufficient long-term resistance, success and comfort [7,10,11]. Many different miniplate types have been designed with varying shapes, sizes, and thicknesses for different indications and regions [12]. Three-dimensional mini-plates have become more popular owing to their ease of use, low volume coverage, and high-level mechanical properties [12,13]. Among these, a newly designed, rhombic-shaped, 3-dimensional (3D) osteosynthesis plate has been presented [14].

Although both the straight and 3D fixation devices have advantages and are frequently used to surgically reduce subcondylar fractures, to the best of our knowledge, no published study has evaluated the biomechanical efficacy of the rhombic-shaped miniplate. Therefore, this study aimed to biomechanically evaluate the fixation resistance and stability of the newly designed miniplate/screw fixation method compared with the conventional double straight miniplate/screw method, both of which are used to surgically treat subcondylar fractures.

Material and Methods

This study was approved by the local ethic committee of Mersin University (No. E-728620. Date: 2018-05-14). Based on related research, the ideal sample size was calculated using G* Power software (Ver.3.1.9.2) to ensure adequate power for the study. Five samples were required in each group, with 5% significance and 80% power.

Experimental and standardized subcondylar fractures were created by removing the coronoid process of ten sheep hemimandible models (Figure 1). The specimens were divided into two fixation groups of five samples each. In one group, double non-locking, four-holed titanium miniplates with eight miniscrews (2 × 5 mm) were applied, and in the other group, single rhombic-shaped titanium non-locking miniplates with five miniscrews (2 × 5 mm) were applied (KLS Martin, Tuttlingen, Germany). The positions of the miniplates and miniscrews were standardized and the plates were shaped. Then, the fragments were fixed according to their groups (Figure 2).

With the help of a fixation device, all hemimandibles were mounted from the corpus region in a servo-hydraulic testing unit (Lloyd Universal Testing Machine, AMETEK, Inc., Hampshire, England) inclined 15° to inferior on the sagittal plane and 10° to lateral on the coronal plane. This positioning was intended to mimic chewing forces on the condyle according to the method defined by Ziccardi et al[15]. A wedge-shaped apparatus was applied to the condylar process and preloaded with 10N. Subsequently, a continuous linear force of 10 mm/min was applied. In all models, straight forces were applied until deformation was observed in miniscrews or miniplates. The displacement and force values were digitally recorded by software integrated into the servohydraulic device.

Statistical analyses were performed using IBM SPSS Statistics (Ver.22.0). Data were tested for normality using the Shapiro–Wilk test. Differences between the groups were analyzed using independent t-tests. The level of significance was set at $p < 0.05$.

Ethical Approval

Ethics Committee approval for the study was obtained.

Table 1. Descriptive Data of the study.

Group Name		Maximum Load (N)	Displacement on Maximum Load (mm)	Stiffness (N/m)
Rhombic Plate	1	151.4	2..67	124940
	2	149.4	3.41	91220
	3	276.9	3.80	131529
	4	232.3	4.11	125213
	5	202.5	3.50	118226
Double Straight Plate	1	318.1	3.48	142890
	2	362.9	5.96	123351
	3	370.9	3.65	171157
	4	311.8	6.58	158607
	5	350.07	4.90	175773
Mean (SD)	Total	272.65 (8.42)	4.21(1.23)	133590 (26067)

Table 2. Comparison of study groups.

		N	Mean (Standard Deviation)	Mean Standard Error	p
Maximum Load (N)	Rhombic Plate	5	202.53 (5.44)	24.354	0.002*
	Double Straight Plate	5	342.77 (2.65)	11.858	
Displacement on Maximum Load (mm)	Rhombic Plate	5	3.5032 (2.57)	11.697	0.082
	Double Straight Plate	5	4.9191 (1.37)	61.315	
Stiffness (N/m)	Rhombic Plate	5	118226.4 (158121)	707173	0.014*
	Double Straight Plate	5	154356.2 (215162)	962244	

Results

Table 1 presents the maximum load (N), displacement at maximum load (mm), and stiffness (N/m) values for the rhombic plate and double straight plate groups in the biomechanical tests.

Table 2 provides the mean, standard deviation, standard error, and comparison results between the groups for the maximum load, displacement on maximum load, and stiffness values. These results showed a significant difference ($p=0.002$) in the maximum load and stiffness. However, there was no statistically significant difference between the groups in terms of the displacement on maximum load values ($p>0.05$).

Figure 1. Establishing the standardized cut line.

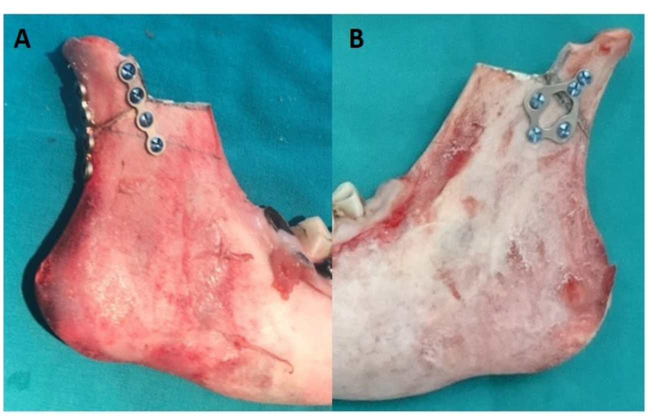

Figure 2. Applications of double straight miniplates and rhombic shaped miniplate.

Discussion

Fracture fixation methods have been evaluated in vitro using two basic methods. In one method, finite element analysis, the complex structure is divided into many simpler, smaller elements and nodes. Therefore, the entire structure may be exposed to virtual forces in the software, and the force distributions, load bearing, and stress zones maybe evaluated objectively and digitally.[13,16,17] The other method involves biomechanical evaluation via a simulation model, prepared with human cadavers, animal bones, or synthetic replica models. One portion of the model was fixed to the testing device, and the vertical load was adjusted to the other portion of the model, which was not fixed. Thus, the shear and compression forces and displacement values of the free ends of the fixed models can be measured using a computer-aided device.[14,18] For this study, the authors chose the biomechanical cantilever beam testing method described by Ziccardi et al.[15], which is highly preferred in the extant literature.

Evidence suggests that a single plate would not be sufficiently stable; therefore, two plates are required to achieve stable fixation.[8,19] However, two straight miniplates (the conventional method) require eight miniscrews, and the necessary materials have a large volume, given the thickness of the condylar region. For this region, there are various three-dimensional designs including trapezoid, deltoid, rhombic-shaped, strut, 9-hole trapezoid, and lambda, etc.[12,20] Recently, a newly designed, rhombic-shaped, 3D miniplate system using five miniscrews has been developed. In a finite element analysis study, which evaluated the displacement values of biting load in a therhombic-shaped miniplate used for mandibular subcondylar fracture, the displacement values were reported as falling between 0.27mm and 1.10 mm.[21] In another finite element analysis study, Abdelwahab et al. compared a rhombic-shaped miniplate to a single straight miniplate and to a double straight mini plate in a mandible subcondylar fracture model. Virtual displacement values were measured as 1.06 mm for the single straight miniplate, 0.20 mm for the double straight miniplate, and 0.40 mm for the rhombic miniplate. The study results suggested that in cases where the thickness of the condyle neck was limited, a single straight miniplate would be unsuccessful; however, a rhombic-shaped miniplate could be biomechanically successful and reliable and could provide appropriate healing.

Halawani et al.[22] reported the clinical results of rhombic-shaped miniplates used for subcondylar and condylar neck fractures in 20 patients. The rhombic miniplates were clinically and radiologically stable and showed satisfactory osteosynthesis. In a randomized controlled clinical trial among 20 patients, Ashor et al.[23] compared rhombic miniplates to double straight miniplates for the treatment of high-level subcondylar fractures, but there were no statistically significant radiological or clinical differences between the groups. The authors suggested that rhombic miniplates could be used because they are advantageous in the presence of thin bones, are easier to apply, reduce operating time, and have economic advantages.

In a similar study planned in parallel to the present study, Achour et al.[14] compared five different methods, including rhombic and double straight miniplate groups. They reported that rhombic-shaped miniplates provided a lower maximum force compared to double straight miniplates; however, there was no statistically significant difference in displacement in the lateromedial or anteroposterior directions. These results were consistent with the present findings; however, force magnitudes differed between the studies because the researchers employed different models (sheep vs. pig).

Conclusion

For subcondylar fractures of the mandible, rhombic-shaped plates showed statistically significantly lower results for maximum force and stiffness compared to double straight plates, which is the conventional treatment method. On the other hand, there were no statistically significant differences between the groups in terms of displacement. Considering this situation as well as the other advantages of rhombic-shaped miniplates (e.g., less volume coverage, fewer necessary miniscrews, and easier surgical application), they may serve as a clinically convenient treatment option for the surgical fixation of subcondylar fractures. This in vitro study should be supported by clinical case reports, case series, and randomized controlled trials for widespread clinical use.

Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and Human Rights Statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of Interest
The authors declare that there is no conflict of interest.

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